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Innovative Applications of O.R.

Scheduling batches in flowshop with limited buffers in the shampoo industry

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ABSTRACT

In this paper we address the problem of planning a temporary storage area in a real production system. This temporary storage area is composed of parallel temporary storage units with distinct capacities. The storage operation of a job, also called a batch, has to answer time restrictions such as release dates, due dates, restricted family dependent setup times and time lags, and also a space constraint which is the capacity of the temporary storage unit. The goal is to schedule the batches on the storage units in order to minimize the total setup times and the maximum lateness. First, we model the problem on a single storage unit as a two-machine flowshop problem with a limited buffer capacity and we show that it is NP-hard. We also show that the particular case in which no lateness is allowed is solvable in polynomial time under special conditions on the buffer capacity, both for single or parallel temporary storage units. Next we provide three heuristics: a greedy algorithm, a hybrid heuristic based on Ant Colony Optimization and Simulated Annealing and finally a dedicated heuristic. The latter strongly exploits the structural properties shown in this paper. We provide experimental results which highlight the efficiency of the dedicated heuristic in comparison with the two other heuristics.

1. Introduction

In this paper we address a scheduling problem occurring in the industry of capillary products production. The overall production system consists in three services: the making, the temporary storage and the packing services. The production process is led by the packing service in which production targets are fixed on the planning horizon according to known deterministic market needs. The planning of the packing service is done under the assumption of enough making and storage capacities. The making service is in charge of producing the products that will later on be packed in bottles by the packing service. The storage service is the interface between making and packing: whenever a product is produced, it is delivered to the storage service before being sent for packing. Everyday, the packing service, which gathers several packing lines, fixes the production for the next 24 hour for each packing line according to its medium term planning. The problem of mid-term planning of the packing lines corresponds to a particular Lot-Sizing Problem as tackled by Mocquillon et al. (2011). Once the production has been fixed, it transmits the planning of orders to be produced (also called batches), one for each packing line, to the making service. Several making units compose the making service and have to produce and transfer the batches to the storage facility. A batch within a storage tank is supplied to the intended packing line according to its planning. A batch is a fixed and indivisible volume (12 tons) of the same kind of shampoo product (also called a *family*). Here, indivisible means that each batch has to be entirely stored in one tank and entirely packed by one packing line. The storage facility contains many tanks with different capacities (12, 20 or 24 tons) and each tank is directly connected to a subset of packing lines. This implies that a batch can only be stored by a given set of tanks depending on the packing line on which it will be processed. Fig. 1 presents a simple example with three making units, five tanks with different capacities, and four packing lines. In this paper we focus on the scheduling problem arising at the level of the storage service.

There are several families of shampoo and each family has its own chemical and physical characteristics. Thus, even if the tank capacity is sufficient, two batches from different shampoo families cannot be stored in it at once. So, in a case where the next batch to be stored belongs to a different shampoo family than the batch previously stored, the tank will have to be cleaned before the arrival of the new batch. In this temporary storage scheduling problem the goal is to minimize the number of tank cleanings and the maximum lateness of the batches. The lateness is defined on the basis of due dates which correspond to the dates at which the packing lines are planned to complete the packing of the batches of shampoo. Limited intermediate storage is crucial in many production process, as in the one dealt with in this paper or more generally in the chemical industry. A cursory glance at the literature highlights the growing interest in tackling limited intermediate storage devices when solving shop scheduling problems. Three

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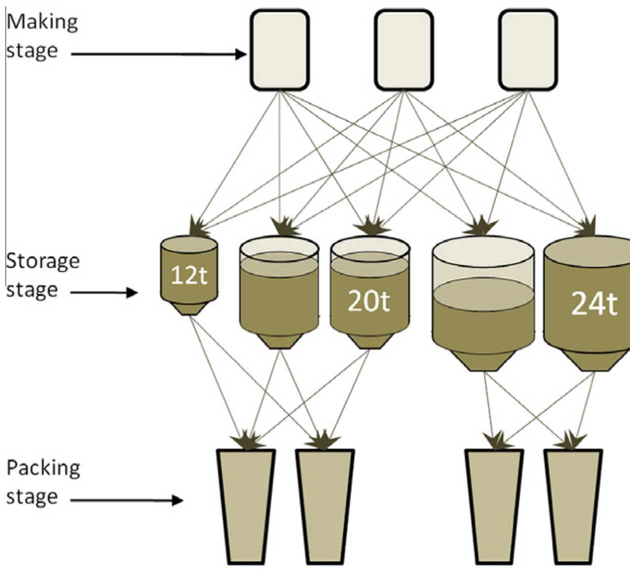

Fig. 1. Simple example of a shop.

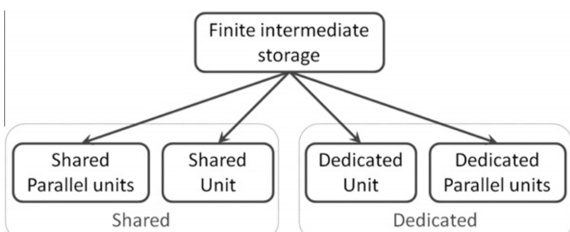

Fig. 2. Categories of FIS.

types of intermediate storage constraints are met in scheduling problems. The first one is the Unlimited Intermediate Storage (UIS): where it is assumed that there is an infinite storage space that can contain all the jobs at any time. The second one is the No Intermediate Storage (NIS): which induces the classical *no-wait* and *block* constraints on the production resources. The last one is the Finite Intermediate Storage (FIS): where it is assumed that there is a limited storage space that can only contain a limited number or quantity of jobs.

The FIS situation can be divided into four categories as presented in Fig. 2. A first decomposition of FIS, as shown in this figure, is based on the interaction between the storage resources and the machines of the shop: this leads to a distinction between shared FIS and dedicated FIS. This decomposition can be refined separating parallel units and unitary resources. The storage resource is said to be *Dedicated* if it is exploitable by at most two consecutive machines in the routings of the jobs.

Two models of dedicated storage emerge: (i) Dedicated single unit storage resources: they correspond to the classical intermediate buffer which is widely considered in the scheduling literature. This model is suitable for shops with different products that can be stored together. (ii) Dedicated parallel units storage resources: here, scheduling the jobs on the storage units might be necessary if nonzero setup costs are considered. This model is very suitable for the chemical industry where different liquid products cannot be stored together. The dedicated parallel units storage resources were considered in the literature by Norman (1999), Ku and Karimi (1988), Kim et al. (1996).

The storage resource is said to be *Shared* if at least three machines in the workshop share its exploitation. We also consider two models for this case: (iii) Shared single unit storage resources: the machines that share the resource are in competition for its use. This model is widely used in computer systems and was considered in printed circuit board manufacturing by Khosla (1995). (iv) Shared parallel units storage resources: several storage units, with different or identical capacities, form a storage stage in a multistage shop. It appears that the storage facility considered in this work is consistent with this model. Other scheduling problems including storage stage were considered in the literature by Pinto et al. (2000), Mendez and Cedra (2000), Ku and Karimi (1990), Lee et al. (1996).

It is obvious that simple models such as *dedicated unit* have been the subject of numerous studies. But models such as *shared parallel units* are more important and complex. They can represent a complete stage in a multistage shop and even be the bottleneck stage. When nonzero transfer times and setups are considered, a storage stage is as important as a processing stage and its scheduling deserves a thorough study. To the best of our knowledge, no study on the scheduling of shared parallel units (FIS) has been presented in the literature. The storage tanks, which are considered in this paper, are then shared parallel (FIS) with particular constraints that will be detailed in Section 2. Noteworthy, these constraints make the problem at the crossroad of three kinds of scheduling problems: scheduling problems with limited buffer capacities, scheduling problems with setup times or costs (see Allahverdi et al., 2008 for a survey) and fixed interval scheduling problems (see Kovalyov et al., 2007, Kolen et al., 2007 for a presentation of the basic problems and results). Regarding scheduling problems with limited buffer capacities, we were more interested in complexity issues for flowshop problems. Papadimitriou and Kanellakis (1980) have shown that the decision problem of the 2-machine flowshop problem with makespan is NP-complete. Gupta (1986) has shown that flowshop problems with sequence dependent setup times or costs are NP-Hard whatever the number of machines, the criteria or the buffer capacity. But no complexity results are known about the particular problem addressed in this paper.

The interest of the piece of research presented in this paper, is that on a complex real-life problem, theoretical results have been established and used to derive an efficient dedicated heuristic. More precisely, we show that a particular case of the problem can be solved in polynomial time an we provide an exact algorithm. This one is then used to solve the general problem in addition with a procedure to repair the infeasibilities eventually created. We also compared this heuristic with suitable implementation of a greedy heuristic and an Ant Colony Optimization heuristic. Noteworthy, the latter has been hybridized with a Simulated Annealing heuristic to improve its efficiency on the tackled problem. However, the conducted computational experiments show the superiority of the dedicated heuristic.

The remainder is organized as follows: Section 2 presents the problem statement and preliminary results; Solution algorithms to solve this problem are outlined in Section 3, while Section 4 is devoted to the computational evaluation of these algorithms. Finally, some conclusions are given in Section 5.

2. Problem statement and properties

2.1. Problem statement and complexity

Consider the problem in which n batches have to be scheduled on L tanks. The buffer capacity of a tank ℓ, $\ell = 1 \dots L$, is denoted by b_ℓ (whenever there is no ambiguity we omit the index ℓ) and, in the same line than the work of Witt and Voss (2007), it is equal to the